

Comparison SAM & Thermoflow for Linear Fresnel (LF) Plants



Speaker



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<http://www.upm.es/observatorio/vi/index.jsp?pageac=grupo.jsp&idGrupo=221>

Presentation outline



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- Introduction (Thermoflow and SAM brief descriptions)
- Solar Field (SF) modeling main capabilities
- Balance of plant (BOP) modeling main capabilities
- LF reference power plant
- Design-Point (21st June, Solar Noon)
- Annual performance
- SAM & Thermoflow capabilities summary
- Conclusions and future work

THERMOFLOW AND SAM BRIEF DESCRIPTIONS

Thermoflow

Thermoflow (1) is a fully flexible software that allows to model a broad range of mass and heat balances in power plants.

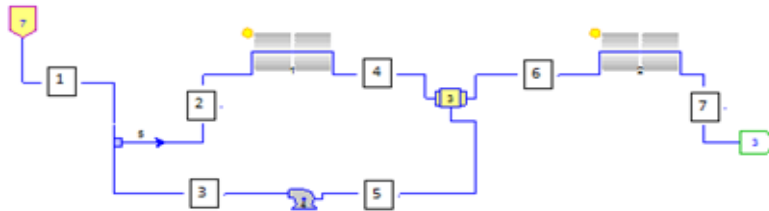


Figure 1. LF DSG recirculation loop model in Thermoflow.

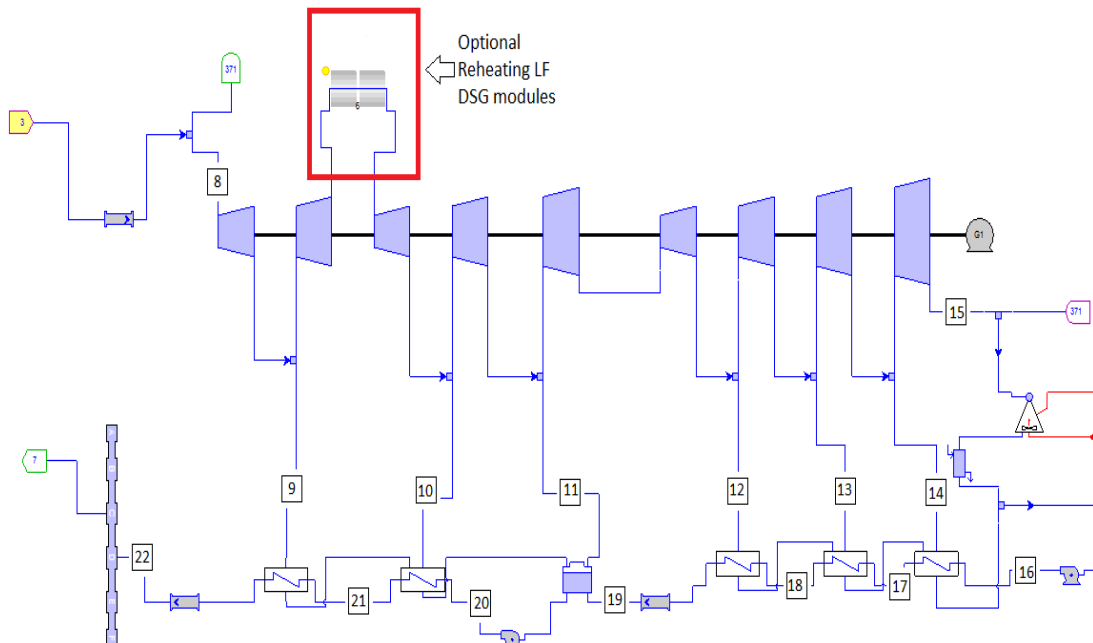


Figure2. BOP model in Thermoflow .

1. Number of IAM data points	91
2. Line collector type: 0=parabolic trough, 1=linear fresnel	1
3. Receiver tube outside diameter	70 mm
4. Receiver tube wall thickness	4.191 mm
5. Aperture width (sum of primary reflector widths)	12 m
6. Aperture width / Collector unit width (Fresnel only)	0.7246 -
7. Collector unit width (for information Fresnel only)	16.56 m
8. Collector focal length	7.4 m
9. Number collector rows per flow path	1 -
10. Number collector row banks	1 -
11. Active reflector length as percent of total length	95 %
12. Collector unit row pitch / collector unit width	1.242 -
13. Reflector cleanliness factor	0.95
14. Row (tracking axis) rotation from due North	0 Degrees
15. Row (tracking axis) tilt from horizontal	0 Degrees
16. Coefficient A1 in heat loss per unit length equation	1 W/m-C
17. Coefficient A2 in heat loss per unit length equation	1.963E-8 W/m-K^4
18. Overall heat loss correction factor	1 -
19. Number of computational segments along receiver	10

Figure 3. LF DSG parameters definition.

SAM

SAM (System Advisor Model). A quasi-steady-state model to estimate LF plants annual performance. Main advantages : reduced computing time, very reliable tool, open source fortran code. Main disadvantages: not graphical environment, not fully-flexible, not energy and mass flows details between equipments.

Location and Resource Location: DAGGETT, CA Lat: 34.9 Long: -116.8 Elev: 588.0 m Solar Field Solar multiple: 1.65 Aperture area: 351,302.4 m ² Collector and Receiver Power Cycle Nameplate: 47.5 MW Parasitics Performance Adjustment Percent of annual output: 96 % Year-to-year decline: 0.28 % per year Linear Fresnel System Costs Total Installed: \$ 157,459,479 Est. per Capacity (\$/kW): \$ 3,313 Financing Analysis: 30 years Solution mode: Specify IRR Target Incentives Fed. ITC No cash incentives Depreciation	Solar Field Parameters <input checked="" type="radio"/> Option 1: <input type="radio"/> Option 2: Solar multiple: 1.65 Field aperture: 862848 m ² Design point irradiation: 950 W/m ² Design point ambient temperature: 25 °C Loop flow configuration: Recirculated boiler Superheater has unique geometry: <input checked="" type="checkbox"/> Number of modules in boiler section: 12 Number of modules in superheater section: 6 The ratio of superheater modules to boiler modules impacts the achievable solar field outlet temperature. Refer to documentation for more info. Field pump efficiency: 0.85 Collector azimuth angle: 0 deg Thermal inertia per unit area of solar field: 2.7 kJ/K-m ²	Design Point Single loop aperture: 9244.8 m ² Loop optical efficiency: 0.642 Loop thermal efficiency: 0.965 Piping thermal efficiency: 0.999 Total loop conversion efficiency: 0.619 Total required aperture, SM=1: 215621 m ² Required number of loops, SM=1: 24 Actual number of loops: 38 Actual aperture: 351302 m ² Actual solar multiple: 1.65 Field thermal output: 206.698 MWt
	Steam Conditions at Design Field inlet temperature: 244.5 °C Field outlet temperature: 500 °C Boiler outlet steam quality: 0.8 Turbine inlet pressure: 90 bar Cold header pressure drop fraction: 0.01	Land Area Solar field area: 86.8087 acres Non-solar field land area multiplier: 1.5 Total land area: 130.213 acres
		Mirror Washing Water usage per wash: 0.007 L/m ² ,ap Washes per year: 120
		Field Control

Figure 4. SAM user interface overview .

SOLAR FIELD MODELING CAPABILITIES

Solar Field (SF) modeling main capabilities

1. Meteorological data loaded from weather files (TMY2, TMY3, etc).

SAM provides this option, and also hyperlinks to official web pages with different countries weather data information. However, Thermoflow not includes this option, but integrates a model developed by Hottel (2) to determine the fraction of extraterrestrial flux reaching the earth at the specified location.

2. SF configuration modeling flexibility.

SAM integrates two alternatives for SF configurations modeling :recirculation parallel loops RC, or once-through (OT) parallel loops, but without water injections to avoid dryout, see DUKE project reference (3). Thermoflow provides a more flexible graphical simulation environment for SF configurations design, showing stream properties (mass, pressure, temperatures, enthalpies) between SF components.

3. Headers and receivers pressure drop models.

SAM calculates pressure drops by means of fixed coefficients for cold headers, hot headers, boiling sections, etc. Thermoflow includes more accurate models: saturated steam pressure drops are calculated with Friedel (4) correlation , Superheated steam and Supercritical water are considered compressible fluids.

4. Receiver Thermal losses.

Both software integrate the capability to calculate thermal losses based on empirical polynomials equations provided by manufacturer (Novatec). But Thermoflow also includes a very accurate model with Kandlikar (5) (for saturated steam) and Dittus Boelter (5) for liquid and superheated steam correlations to calculate Heat Transfer Coefficients (HTC) in receivers pipes.

(2) Hottel, H.C., A Simple Model for Estimating the Transmittance of Direct Solar Radiation Through Clear Atmospheres, *Solar Energy*, Vol 18, pp. 129-134, Pergamon Press, 1976

(3) "Concept comparison and test facility design for the analysis of Direct Steam Generation in Once-Through mode". Jan Fabian Feldhoff (1), et al. German (DLR),CIEMAT, SolarPACES 2012.

(4) Friedel's method described by Whalley, P.B., Boiling, *Condensation and Gas-Liquid Flow*, Oxford University Press, 1987

(5) Dittus-Boelter equation from Lienhard, John, H., *A Heat Transfer Textbook, 2nd Edition*, Prentice-Hall, Inc., 1987

Kandlikar, Satish, G., A General Correlation for Saturated Two-Phase Flow Boiling Heat Transfer Inside Horizontal and Vertical Tubes, *Journal of Heat Transfer*, February 1990, Volume 112, p. 219-229

LF DSG Solar Field (SF) modeling capabilities

5. SF operational limits.

SF real behaviour is represented by SAM by means of the following parameters: flow limiting, stow and deploy angles limits, freezing limit, stow wind, etc. These options are not provided in Thermoflow. Most of the listed parameters limits impact widely under low Sun radiation conditions. As a further improvement, stratified flow or annular flow could be predicted by software according to water pressure and enthalpy conditions.

6. Reflector “end losses” factor.

SAM integrates LF end losses calculations in Incident Angle Modifiers (IAM), as indicated in Novatec brochure. However, Thermoflow calculates explicitly this factor according with the following equations (6):

$$\eta_{opt} = \eta_{nominal} * IAM(\theta_{\perp} \theta_{||}) * f_{clean} * f_{end\ loss}$$

$$\eta_{end-loss} = 1 - \tan(\theta_i) \frac{D_{pm}}{L_{abs}},$$

where D_{pm} is the distance of primary mirrors from the tube absorber, and L_{abs} represents the receiver length.

7. SF thermal inertia.

Thermoflow doesn't include this capability. SAM, considers a value of 2.7 kJ/K m² for thermal inertia per unit area of solar field. Thermal inertia depends on receiver material and could be detailed computed by the software tool depending on material selection.

LF DSG Solar Field (SF) modeling capabilities

8. Receiver material selection , stress analysis, and wall thickness calculation.

Thermoflow allows user to select different receiver materials (Carbon steel, or other stainless steels: Super 304H, TP 347 HFG, T91, etc), and also pipes stress analysis and wall thickness for operating pressures are calculated. SAM doesn't consider stress analysis as a limiting variable in LF SF design.

9. Incidence Angle Modifiers (IAM).

Three options are provided by SAM in order to compute IAM values:

- a) IAM depending on Sun position angles (zenith and azimuth).
- b) IAM based on collector incidence angles (longitudinal and transversal incident angles) .
- c) Incidence angle modifiers polynomials approach.

See in the following slide (Table 1 and 2), IAM values for Novatec LF collectors, from SAM and Thermoflow.

Thermoflow only integrates b) option. This option is validated by information supplied by Novatec. As a improvement we propose to integrate analytical IAM models (like FirstOptic code) or montecarlo model (SolarTrace) within SAM or import/export IAM values.

10. SF parasitic losses.

Tracking power loss and piping thermal loss coefficient are explicitly inputted by user in SAM, not in Thermoflow.

11. Turbine inlet temperature limited by receiver's selective coating materials.

In Thermoflow is possible to limit superheated steam temperature leaving superheater LF modules. SAM doesn't allow to fix this limit, only field outlet design temperature could be provided by user, but under part-load conditions this temperature limit is superseded.

LF DSG Solar Field (SF) modeling capabilities

Table 1. Incidence Angle Modifiers IAM table (SAM).

0	0	10	20	30	40	50	60	70
0	1	0.97894	0.95382	0.94864	0.91162	0.86104	0.7036	0.48456
10	0.97791	0.95732	0.93275	0.92768	0.89148	0.84202	0.68806	0.47386
20	0.92189	0.90247	0.87932	0.87454	0.84041	0.79378	0.64864	0.44671
30	0.83049	0.813	0.79214	0.78784	0.75709	0.71509	0.58433	0.40242
40	0.70119	0.68642	0.66881	0.66518	0.63922	0.60375	0.49336	0.33977
50	0.5336	0.52236	0.50896	0.50619	0.48644	0.45945	0.37544	0.25856
60	0.32563	0.31877	0.31059	0.30891	0.29685	0.28038	0.22911	0.15779
70	0.1173	0.11483	0.11188	0.11128	0.10693	0.101	0.08253	0.05684
80	0.01103	0.0108	0.01052	0.01046	0.01006	0.0095	0.00776	0.00534
90	0	0	0	0	0	0	0	0

Specifying collector incidence angle table: Rows indicate longitudinal incidence angles (deg), columns indicate transversal incidence angles (deg)

Table 2. Incidence Angle Modifiers IAM table (THERMOFLOW).

Angle	IAM	IAM
Degrees	Longitudinal	Transverse
0	1	1
1	0.999	0.994
2	0.998	0.983
3	0.997	0.973
4	0.995	0.971
5	0.993	0.971
6	0.991	0.977
7	0.988	0.988
8	0.985	0.996
9	0.982	0.992
10	0.978	0.98
11	0.974	0.97
12	0.97	0.967
13	0.965	0.965
14	0.96	0.97
15	0.955	0.981

15	0.955	0.981
16	0.949	0.986
17	0.943	0.979
18	0.936	0.965
19	0.929	0.958
20	0.922	0.956
21	0.915	0.955
22	0.907	0.963
23	0.899	0.97
24	0.89	0.967
25	0.88	0.952
26	0.871	0.945
27	0.862	0.943
28	0.852	0.941
29	0.841	0.951
30	0.831	0.951

LF DSG Solar Field (SF) modeling capabilities

12. Number of discretization nodes to compute energy flows in receivers pipes.

Thermoflow defines a user input parameter to define the number of segments to subdivide the receiver to calculate water properties along receiver length, and heat losses. This parameter is very important to obtain accurate heat transfer coefficients, compressible pressure drops, and energy fluxes in receiver.

SAM identifies number of boiling and superheating modules with only one node. This model could be improved by means of increasing number of nodes inside each module.

13. Parallel loops input parameters.

In Thermoflow is possible to define different parameters for each LF module or loops. For example incident DNI could vary from one loop to the other. Also cleanliness factor differences between loops could impact in SF behaviour. All these facts cannot be modeled in SAM.

14. Collector orientation respect North.

Thermoflow includes two parameters to define collector azimuth angle respect north and tilt angle. In SAM are not programmed these two orientation options.

15. Multitubes LF configuration (7).

Neither SAM nor Thermoflow allow to define a physical multitube LF model. Only polynomial equations to define heat losses or pressure drops could be selected to simulate this kind of solar collector.

BOP MODELING CAPABILITIES

Balance of plant (BOP) modeling capabilities

1. Innovative regresion model to estimated plant annual performance.

SAM integrates an estimative BOP model to reduce computing time for anual plant performance calculations. This model could be programmed in Thermoflow in order to improve the Excel link (E-Link) option available to perform this kind of annual estimations.

2. BOP operation modes (start up, shut down, stand by, etc).

SAM Start-Up energy takes into account thermal inertia to heat-up receivers and headers, and also heating energy required during transitory Sun radiation periods. These energy flows are considered in Thermoflow.

3. BOP Direct Reheating LF modules (8).

SAM doesn't provides this option for LF power plants. Reheating improve power plant efficiency and power output. In Thermoflow Direct Reheating could be modeled, as well as indirect reheating with a heat exchanger.

4. Condenser part-load levels.

SAM simulates air condenser real behaviour. User can input number of part load levels. Also a minimum limit vacuum pressure could be fixed. Thermoflow also offers off-line condenser performance but not allow the two mentioned options.

5. BOP parasitic energy looses.

Differences in BOP and SF parasitic energy looses definitions in both software are identified. More detail information will be showed in the following slides. Air condenser Fan power calculations differs in both tools. Due to lack of information in air condenser air stream properties not permit to find energy flux differences.

Balance of plant (BOP) modeling capabilities



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6. BOP equipments performance curves for operation under part-load scenarios.

During part-load conditions BOP equipments performance parameters (turbine stages efficiencies, heat exchanger TTD and DCA, pumps efficiencies, etc) varies respect to nominal power conditions. These variations should be considered for SAM BOP regression model. Also in Thermoflow is possible to achieve BOP equipments technology improvements analysis because all equipment performance parameters could be adjusted during annual performance calculations.

7. Thermal Energy Storage (TES) integrated in LF DSG power plant (9).

Thermoflow integrates different equipments to model TES system. This option is not considered in SAM for DSG LF plants.

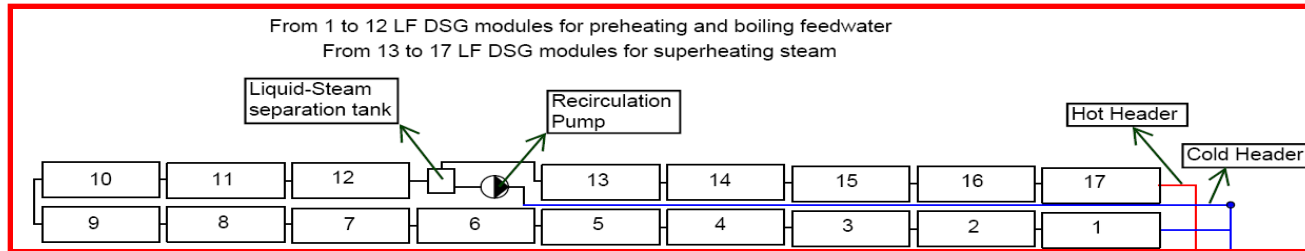
8. SF and BOP cost and financing model.

SAM is the better tool to make an economical estimation approach for LF power plants. Thermoflow cost model doesn't show the level of details available in SAM.

REFERENCE LF POWER PLANT

(26 recirculation parallel loops)

Reference LF power plant (26 parallel recirculation loops)



Location: Dagget, CA, USA

Gross Power: 50 Mwe

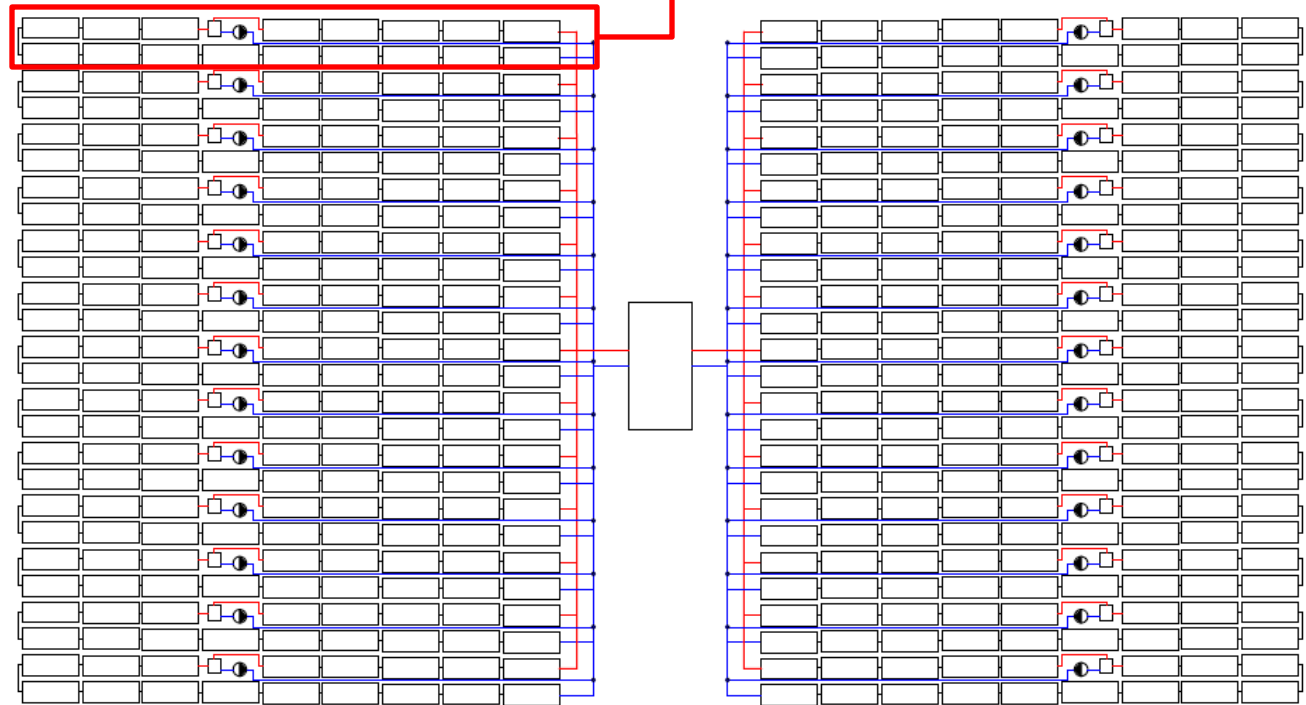
Net Power: 47,5 Mwe

Solar collector: LF DSG Novatec

Solar Field effective aperture
area: 227.100 m²

Superheated steam at turbine
inlet:

- Pressure : 90 bar
- Temperature: 500 °C



DESIGN-POINT PERFORMANCE

(21st June, Solar Noon)

Design-Point (21st June, Solar Noon)

1. OPTICAL PERFORMANCE.

SAM defines a variable called **MidTrack** (time at midpoint of operation). Thermoflow doesn't consider this variable, and for comparison between both software tools, max. DNI at solar Noon was considered 986 W/m² at 11:30 am. Also SF stow and deploy limiting angles were not defined. In the following Table Solar Noon conditions are listed.

Time	11:30 am
DNI	986 W/m ²
Relative humidity	18 %
Dry bulb temperature	31.95 °C
Wet bulb temperature	16 °C
Site Altitude	588 m

Table 3. Solar Noon conditions.

Sun and incident angles calculation in both software shows the same values. These values are calculated for 11:30 am (MidTrack). See Table 2 .

	Thermoflex	SAM
Elevation	77.88 deg	77.91 deg
Zenith angle	12.12 deg	12.092 deg
Azimuth angle	159.1 deg	159.12 deg
Long. incident angle	11.31 deg	11.31 deg
Transv. Incident angle	4.372 deg	4.372 deg

Table 4. Solar Noon Sun angles. Results validated with SolPos (NREL) algorithm :<http://www.nrel.gov/midc/solpos/solpos.html>

Design-Point (21st June, Solar Noon)

Real optical efficiency (Thermoflow) = Nominal optical efficiency x cleanliness factor x end losses factor x IAM

Real optical efficiency (SAM) = Nominal optical efficiency x cleanliness factor x tracking error factor x geometry effects factor x mirror reflectivity factor x mirror soiling factor

Thermoflow not consider the following factors in real optical efficiency: tracking error factor, geometry effects factor, mirror reflectivity factor, mirror soiling factor.

IAM calculations (Thermoflow):

Long. Incident angle 11.31 deg. : IAM long. =0.974

Transv. Incident angle 4.372 deg. : IAM transv. =0.971

IAM long. X IAM transv. = 0.974 x 0.971 = 0.945

IAM calculations (SAM):

Long. Incident angle 11.31 deg. (table rows)

Transv. Incident angle 4.372 deg. (table columns)

IAM = 0.96

Table 5. Boiling modules real optical efficiency.

	Thermoflex	SAM
Optical Efficiency	67 %	67 %
Cleanliness factor	96 %	96 %
End Losses Factor	99.45 %	n/a
IAM	94.45 %	96 % (deducted)
Real optical efficiency (%)	60.42 %	61.74 %

Table 6. Superheating modules real optical efficiency.

	Thermoflex	SAM
Optical Efficiency	65 %	65 %
Cleanliness factor	96 %	96 %
End Losses Factor	98.71 %	n/a
IAM	94.45 %	96% (deducted)
Real optical efficiency (%)	58.18 %	59.9%

Design-Point (21st June, Solar Noon)

2. THERMAL PERFORMANCE.

Incident Energy is very similar values in both tools.

$$Q_{\text{inc.}} = \text{DNI} \times \text{Effective aperture area} = 227.100 \text{ m}^2 \times 986 \text{ W/m}^2 = \\ Q_{\text{inc.}} = 223.92 \text{ MWth}$$

Received energy differs in both software due to endlosses factor:

$$Q_{\text{rec. (SAM)}} = Q_{\text{inc.}} \times \text{nominal optical efficiency} \times \text{IAM} \times f_{\text{cleanless}} \\ \times f_{\text{track}} \times f_{\text{geom effects}} \times f_{\text{mirror reflectivity}} \times f_{\text{mirror soiling}} = \\ Q_{\text{rec. (SAM)}} = (166000 \text{ m}^2 \times 986 \text{ W/m}^2 \times 0.67 \times 0.96 \times 0.96 \times 1 \times 1 \times 1 \times 1) \text{ (boiling modules)} + \\ (61000 \text{ m}^2 \times 986 \text{ W/m}^2 \times 0.65 \times 0.96 \times 0.96 \times 1 \times 1 \times 1 \times 1) \text{ (superheating modules)} = 137.1 \text{ MWth} \\ Q_{\text{rec. (Thermoflow)}} = Q_{\text{inc.}} \times \text{nominal optical efficiency} \times \text{IAM} \times f_{\text{cleanless}} \times f_{\text{endlosses}} = \\ Q_{\text{rec. (Thermoflow)}} = (986 \text{ W/m}^2 \times 161644 \text{ m}^2 \times 0.6042) \text{ (boiling modules)} + \\ (986 \text{ W/m}^2 \times 65674 \text{ m}^2 \times 0.5818) \text{ (superheating modules)} = 133.9 \text{ MWth}$$

SF Thermal power = SF Received Energy – SF Thermal Losses

$$\text{SF Thermal power (SAM)} = 137.18 \text{ MWth} - 6.71 \text{ MWth} = 129.78 \text{ MWth (see Note)}$$

$$\text{SF Thermal power (Thermoflow)} = 133.92 \text{ MWth} - 6.6 \text{ MWth} = 127.3 \text{ MWth}$$

	Thermoflex	SAM
SF Incident energy	224.07 MWth	223.83 MWth
SF Received energy	133.92 MWth	137.18 MWth
SF Thermal losses	6.6 MWth	6.71 MWth (see Note)
SF Thermal power	127.32 MWth	129.78 MWth

Table 7. SF energy flows.

Note: SF piping heat losses are also included in SF Thermal losses and Start-up Energy.

Design-Point (21st June, Solar Noon)

Gross Power (SAM) = SF Thermal Power x Gross Efficiency = 129.78 MWth x 0.3972 = 51.54 Mwe

Gross Power (Thermoflow) = SF Thermal Power x Gross Efficiency = 127.32 MWth x 0.395 = 50.29 Mwe

Net Power (SAM) = Gross Power – Cooling system parasitic load- Parasitic pumping power-Fixed parasitic power- Collector field parasitic power-Load dependent parasitic power- Aux boiler parasitic power

Net Power (SAM)= 51564 kWe – 2708.25 kWe – 131.93 kWe– 283.25 kWe – 45.4 kWe -0-0= 48395 kWe

Net Power (Thermoflow) = Gross Power – Fan Power – Condenser Pump power – Feedwater pump power- SF parasitics – Fixed BOP parasitics (1% Gross power)

Net Power (Thermoflow) = 50284 kWe – 1599.7 kWe – 61.76 kWe – 718.1 kWe – 15.11 kWe – 502.84 kWe = 47386.5 kWe

Total parasitic power (SAM) = 51564 kWe – 48395 kWe = 3168.83 kWe

Total parasitic power (Thermoflow) = 50284 kWe – 47386.5 kWe= 2897.51 kWe

BOP	Thermoflex	SAM
Gross Power	50284 kWe	51564 kWe
Gross Efficiency	39.5 %	39.72 %
Net Power	47387 kWe	48395.1 kWe
Net Efficiency	37.23 %	37.3%
Fan Power	1599.7 kWe	2708.25 kWe
Condenser Pump	61.76 kWe	131.93 kWe
Feedwater Pump	718.1 kWe	45.4 kWe
SF parasitics	15.11 kWe	283.25 kWe
Fixed parasitics	502.84 kWe	

Table 8. BOP energy flows.

ANNUAL PLANT PERFORMANCE

Annual plant performance

2% deviation in Gross Power

4% deviation in Net Power

Main differences: collector end losses, thermal inertia (start-up energy) and parasitic losses.

Table 9. LF plant annual performance.

	Thermoflex Gross Power (MWh)	SAM Gross Power (MWh)	Thermoflex Gross Power (MWh) *	Thermoflex Net Power (MWh)	SAM Net Power (MWh)	Thermoflex Net Power (MWh) *
January	2438	2336	2294	2330	2205	2189
February	3649	3577	3498	3482	3389	3334
March	6053	5871	5881	5769	5546	5600
April	8132	8009	7982	7721	7495	7573
May	10396	10282	10263	9838	9531	9705
June	11650	11539	11529	10930	10613	10807
July	11001	10772	10848	10273	9903	10119
August	10973	10848	10858	10282	9985	10166
September	8420	8324	8272	7933	7651	7786
October	5651	5404	5481	5363	4969	5197
November	3324	3024	3193	3173	2850	3045
December	2290	2275	2164	2187	2124	2063
TOTAL	83977	82260	82263	79281	76262	77584

(*) Bypass in last Low Pressure LP turbine stage, to avoid negative power.

SAM & THERMOFLOW CAPABILITIES SUMMARY

SAM & Thermoflow capabilities summary

Comparison of capabilities for LF DSG power plant design.

	Thermoflex	SAM
Graphical simulation environment showing energy streams properties	Yes	No
SF configuration modeling flexibility	Yes	No
Meteorological data directly loaded from weather files (TMY2, TMY3, EPW)	No	Yes
SF thermal inertia consumed during start up, shut down and radiationtransitory	No	Yes
SF pressure drop accurate models (saturated steam Friedel correlation, compressible superheated steam, etc)	Yes	No
SF control parameters (flow limit, stow and deploy limit, freezing limit, stow wind, etc)	No	Yes
Receiver heat losses accurate model (Kandlikar, Dittus-Boelter HTC correlations)	Yes	No
Receiver tubes thickness calculation and stress limit.	Yes	No
BOP Off-Line annual performance innovative regression model capability	Yes	No
BOP operational modes (start up, shut down, stand by, etc)	No	Yes
SF and BOP parasitic energy losses detail (tracking power, etc)	No	Yes
Supercritical water SF and BOP simulation	Yes	No
BOP reheating LF DSG modules	Yes	No
Condenser part load levels	No	Yes
Financial, incentives, depreciation models	No	Yes

CONCLUSIONS AND FUTURE WORK

Conclusions and future work

Synergies between both software tools development would be a chance to improve SAM and Thermoflow capabilities.

SF and BOP control and operation limits should be included in LF DSG software design tools.

Simulation tools should consider low Sun radiation days with different SF and BOP configuration requirements.

Reduced-Order Power Block Performance Models for CSP Applications (Michael J. Wagner) was validated for DSG LF power plants.

LF Optical performance simulation with analytical or Montecarlo methods, like FirstOptic or SolarTrace, could be integrated in Thermal Balance software tools like SAM and Thermoflow.

Stress analysis limits should be imposed in Thermal Balances simulation software to obtain an optimised and feasible LF DSG power plant design.